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RESEARCH MEMORANDUM

AN EMPIRICAL CRITERION FOR FIN STABILIZING JETTISONABLE NOSE SECTIONS OF AIRPLANES

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AN EMPIRICAL CRITERION FOR FIN STABILIZING JETTISONABLE NOSE SECTIONS OF AIRPLANES

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SUMMARY

Investigations in the Langley 20-foot free-spinning tunnel of models of five jettisonable nose sections have shown that airplane nose sections are inherently unstable but can be stabilized by the addition of suitable fins. An empirical criterion has been developed which indicates the fin area required for stabilizing an airplane jettisonable nose section.

INTRODUCTION

A proposed method of providing for emergency pilot escape from high-speed airplanes consists of jettisoning the nose section of the fuselage clear of the remainder of the airplane, with the break-off station just rearward of the pilot's station; the pilot leaves the nose section after it has decelerated to a safe speed. Recently, the low-speed behaviors of five models of possible jettisonable nose configurations for single-seat transonic airplanes have been investigated in the Langley 20-foot free-spinning tunnel, and it has been noted that each model descended in the vertically rising air stream with some type of rotary motion (reference 1 and unpublished data). More recent results (data unpublished) have indicated that the rotary motion of a jettisoned unstable nose at high speeds may not necessarily be similar to that indicated at low speed, but that even if the nose does not rotate it will tend to trim away from a nose-first flight attitude which may cause decelerations dangerous to the pilot. Analysis indicates that if a nose jettisoned at transonic speeds could be made to continue flying in a nose-first attitude, the deceleration would not be excessive and, in addition, the deceleration would act on the pilot's body in the direction (transverse) in which human tolerance to acceleration is highest.

In the present investigation, the testing technique and test results for the five models at low speed are briefly reviewed, and an empirical criterion based on consideration of these results has been prepared which relates the effects of fin design and of center-of-gravity location on the stability of airplane jettisonable nose sections. Curved fins (simulating fins which would normally be folded flush with the fuselage and extended during an emergency requiring jettisoning of the nose) were used in some of the tests. Recent NACA work on some of the high-speed aspects of fin stabilization of a jettisonable nose is also discussed. The problem of providing for clean separation between nose and airplane is beyond the scope of the present paper.

SYMBOLS

X, Y, Z	longitudinal, lateral, and normal axes, respectively, through center of gravity of nose
k_X, k_Y, k_Z	radii of gyration of nose about X-, Y-, and Z-axes, respectively, inches
n	fineness ratio of nose, excluding canopy or other protuberance (for circular cross section, Length/Diameter; for non-circular cross section, Length/Maximum cross dimension)
L	length of nose section, feet (All center-of-gravity locations are expressed as a percentage of this length from the front end of the nose section.)
S_F	smallest projected fin area in any plane parallel to longitudinal axis
S_P	projected area of nose (excluding protuberances) in plane of smallest projected fin area
L_T	projected distance between centroid of S_F and center of gravity of nose
$\frac{S_F L_T}{S_p L}$	fin-stabilization factor (fig. 1)
α	angle of attack of nose X-axis, degrees
C_m	pitching-moment coefficient as determined graphically

C_{m_α}	rate of change of pitching-moment coefficient with angle of attack in degrees $\left(\frac{dC_m}{d\alpha}\right)$
$\frac{dA}{dx}$	rate of change of nose cross-sectional area with nose length
ϵ	angle between tangent to nose surface in plane of symmetry and nose X-axis, degrees
x	distance from front of nose to any station, feet
a	distance from front of nose to center of gravity, feet
ΔF	normal force per unit length
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
ρ	density of air, slugs per cubic foot
V	airspeed, feet per second
C_{L_α}	rate of change of lift coefficient with angle of attack in degrees $\left(\frac{dC_L}{d\alpha}\right)$
S_{F_t}	area of one nose fin

MODELS AND METHODS

The models tested represented $\frac{1}{10}$- to $\frac{1}{23}$-scale models of possible airplane jettisonable nose sections. They were made of balsa and hardwood and ballasted with lead weights to simulate relative mass arrangements of the possible nose configurations at an altitude of 15,000 feet. The models had circular or near-circular cross sections and some had canopy portions or other protuberances. Sketches and mass characteristics of the models are presented in table I.

During the tests, each model was held in the air stream of the Langley 20-foot free-spinning tunnel at various angles of attack from 0° to 180° and then released; the model was also launched with rotation applied about each of its three axes with the axes held alternately parallel with and perpendicular to the air stream. The behavior of the model in the air stream was observed after each launching, after which the air-stream velocity was lowered and the model caught in a safety net and retrieved for the next launching. A photograph showing the test section of the free-spinning tunnel with an airplane model spinning in the tunnel is shown in figure 2.

Various combinations of fin installations and center-of-gravity locations were investigated to determine arrangements which would make each model descend in a stable nose-down manner. It is recognized that the use of fins on an airplane jettisonable nose section will require that the airplane either be constructed so that satisfactory flight characteristics can be obtained with the fins installed or that the fins be initially retracted and be extended immediately as the nose separates from the rest of the airplane. The type of fin arrangement found during the tests to be most effective in stabilizing the models, and hence used in the present study, consisted of four or three fins placed on the side of the nose section, generally at 90° or 120° intervals, respectively, around the periphery of the nose section at the break-off station. Sketches of the various types of fin arrangements tested are shown in figure 3. Arrangements d and e in figure 3 illustrate methods of mounting fins on a protuberance. Arrangements g, h, and i in figure 3 simulate curved retractable fins. A fairly wide range of fin aspect ratios, 0.4 to 2.0 (based on the span and area of each fin), was covered during the tests. For all the tests in which curved fins were installed on the models, four fins were used with two being curved in each direction in order to avoid unbalanced rolling moments such as might occur if the number of fins curved in each direction were not equal. In order to obtain a direct comparison of the relative stabilizing effectiveness of curved and flat fins, some of the tests with curved fins were made with the fins installed at 90° intervals on the nose periphery (arrangement g in fig. 3) in such a manner that they had the same profile shape and projected area in a radial plane as a corresponding flat-fin arrangement (arrangement c in fig. 3). The span of all the curved fins tested was small enough so that they would not overlap when retracted against the fuselage.

A factor indicating the relative effectiveness of a given fin design was determined for each condition tested. This factor, hereinafter called the fin-stabilization factor $\left(\frac{S_F L_T}{S_p L}\right)$, was determined by the method illustrated in figure 1 and is the ratio of the smallest projected fin area in any plane parallel to the longitudinal axis multiplied by the projected distance between the centroid of this area and the model center of gravity to the projected area of the model (excluding protuberances) in the plane of smallest projected fin area multiplied by the length of the model. For the fin arrangements in which four flat fins were installed on the nose-section periphery at 90° intervals and for the curved-fin arrangement in which the fins had the same location, profile shape, and projected area in a radial plane as the flat-fin arrangement, the plane of the smallest projected fin area was a plane which made a 45° angle with a plane through either pair of opposite fins. (See fig. 1.) For the remaining flat- and curved-fin arrangements, the plane of the smallest projected fin area was determined graphically for each condition tested. When a fin was mounted on a protuberance (arrangements d and e in fig. 3), it was arbitrarily considered to have the same projected area forward of the break-off station as did the fins at the other periphery intervals. The fin-stabilization factor was plotted against the center-of-gravity location for each condition tested, with different symbols being used to indicate whether or not the model descended in a stable nose-down attitude.

RESULTS AND DISCUSSION

A brief résumé of the results of Langley 20-foot free-spinning-tunnel tests of models simulating possible airplane jettisonable nose sections without stabilizing fins is included in table I. As shown in the table, some of the models descended with tumbling motions about their lateral or normal axis; whereas others trimmed at a high angle of attack and rolled about their longitudinal axis. The latter condition was obtained only with those models which had a canopy portion or other protuberance. The protuberances apparently excited a rolling moment which developed into an equilibrium rotation. When a suitable arrangement of stabilizing fins and center-of-gravity location was used, the models descended in a stable nose-down attitude without rolling. The results indicated that curved and flat fins having projected areas of the same magnitude and direction were equally effective in stabilizing a nose section.

The plot of fin-stabilization factor against the center-of-gravity location was examined and it was seen that for all the results except those for model 2, a boundary could be drawn which fairly well separated the regions for which stable nose-down descent was and was not obtained. It was noted that all the other models differed from model 2 primarily in that their fuselages extended forward almost to a point at their front end; for model 2, then, the fin-stabilization factors and center-of-gravity locations were recalculated by using an assumed altered body shape in which the model's profile lines extended forward until they too intersected at a point. The recalculated fin-stabilization factors were plotted and the conditions for stable and unstable descent for model 2 then fell in the same regions obtained by drawing the boundary line for the other four models. The plot and boundary line are presented in figure 4.

As can be seen in figure 4, the results of the study indicate that it is difficult to achieve nose-down stability of an inherently unstable nose section by merely moving the center of gravity forward; the results also indicate that if the center of gravity is too far rearward even very large fins might not make a nose section stable.

In addition to the fin-stabilization factor and the center-of-gravity location, it is expected that other factors, such as mass distribution, fineness ratio, and body lines, may affect the boundary in figure 4 somewhat but are apparently of only secondary importance. The fin-stabilization factor is proportional to the static longitudinal stability factor C_{m_α}, except for omission of the C_{L_α} term which normally is greatly influenced by aspect ratio. The present empirical results, however, did not indicate an appreciable effect on the boundary of varied fin aspect ratio within the range investigated. From these results, it appears that the boundary may be used as an empirical criterion to indicate the fin area required to stabilize an airplane jettisonable nose section having a pointed front, and from the interpretation of results obtained with model 2, it appears that the boundary may also be used to obtain an indication of the fin area required for stabilizing a nose section with other than a pointed front.

Another possible method of approach to the problem of selecting suitable stabilizing fins for a specific nose design might consist of calculating the instability of the nose section and the stabilizing effect of the fins. In such a method, it will probably be necessary to consider both static- and dynamic-stability parameters or use some empirical correction to allow for the dynamic-stability effects. In order to illustrate a possible approach, brief static-stability calculations have been made for model 1 of the present investigation, with and without a set of four triangular stabilizing fins of arrangement a installed. The span of the fins considered was 27 percent of the nose length and the aspect ratio was 2.

The instability of the nose section without fins was calculated by the equation

$$C_{m_\alpha} = \frac{2}{S_p L} \int_0^L \frac{dA}{dx} \left(\cos^2\epsilon\right)(a - x)dx$$

where C_{m_α} was determined graphically. This equation is similar to one developed and applied to a jettisonable nose section in reference 2 based on the relationship from reference 3

$$\Delta F = q \frac{dA}{dx} \cos^2\epsilon \sin 2\alpha$$

where ΔF can be taken as a measure of the transverse or normal force per unit of length for a symmetrical airship hull.

The stabilizing effectiveness of the fin system was calculated by the following general equation:

$$C_{m_{\alpha_{fins}}} = -2C_{L_{\alpha_{fins}}} \cos^2\theta \frac{S_{F_t} L_T}{S_p L} - 2C_{L_{\alpha_{fins}}} \cos^2\phi \frac{S_{F_t} L_T}{S_p L}$$

where θ is the angle between the plane of any two of the fins and the axis about which C_{m_α} is calculated and ϕ is the angle between the plane of the other two fins and this axis. The angle θ plus ϕ equals 90°. Therefore,

$$C_{m_{\alpha_{fins}}} = -2C_{L_{\alpha_{fins}}} \frac{S_{F_t} L_T}{S_p L} \left(\cos^2\theta + \cos^2\phi\right)$$

and since

$$\theta = 90 - \phi$$

and

$$\cos\phi = \sin\theta$$

then

$$C_{m_{\alpha_{fins}}} = -2C_{L_{\alpha_{fins}}} \frac{S_{F_t} L_T}{S_p L} \left(\cos^2\theta + \sin^2\theta\right)$$

Also, since

$$\cos^2\theta + \sin^2\theta = 1$$

then

$$C_{m_{\alpha_{fins}}} = -2C_{L_{\alpha_{fins}}} \frac{S_{F_t} L_T}{S_p L}$$

In terms of the parameter S_F which was used in the empirical criterion of the present investigation, since S_F is equal to $2S_{F_t} \cos 45^{\circ}$, the stabilizing effectiveness of the fins could have been calculated by

$$C_{m_{\alpha_{fins}}} = -2C_{L_{\alpha_{fins}}} \frac{S_F L_T}{2 \cos 45^{\circ} S_p L}$$

$$= -C_{L_{\alpha_{fins}}} \frac{S_F L_T}{\cos 45^{\circ} S_p L}$$

The values used for $C_{L_{\alpha_{fins}}}$ were obtained from reference 4 which presents the variation of C_{L_α} with aspect ratio for low-aspect-ratio wings. Based on information in reference 5, the aspect ratio of each fin was assumed to be effectively 1.5 times its geometric aspect ratio in order to allow for increased fin lift effectiveness caused by end-plate effects of the nose. The calculated stabilizing contribution of the fins was added to the calculated instability of the nose to obtain the resultant C_{m_α} for the finned nose.

The calculated C_{m_α} values for the nose with and without fins for two center-of-gravity locations are plotted in figure 5. On the figure the finned nose is indicated as being statically stable for both center-of-gravity locations investigated. The empirical results obtained with model 1, however, indicated that only for the more forward center-of-gravity location did the finned nose damp applied rotation and descend in a stable nose-down attitude. It thus appears that dynamic stability must be given consideration either through calculations or through empirical corrections. For comparison with the calculated values, measured values of C_{m_α} obtained from force and moment tests of a large model similar to model 1 with and without fins are also plotted in figure 5. As can be seen, the calculated and measured values of C_{m_α} for the nose without fins were in fairly close agreement. Values of C_{m_α} measured for the nose section with the fins installed indicate that adding the fins had a greater stabilizing effectiveness than was indicated by the calculations, probably because interference effects of the fins on the flow over the nose section caused an additional increase in the stabilizing effectiveness of the fins.

The aforementioned work has been done on the basis of free-spinning-tunnel tests at airspeeds up to 60 miles per hour which, based on a scale range of about 1/10 to 1/23 for the various dynamic models tested, correspond to full-scale airspeeds up to 300 miles per hour. However, it is interesting to note that preliminary analysis of recent NACA higher-speed investigations has also indicated that fins were effective in stabilizing nose sections. In one instance (results unpublished), a smaller model of one of the free-spinning-tunnel nose sections was released with and without stabilizing fins in an atmospheric horizontal wind tunnel at sea-level airspeeds up to 150 miles per hour, simulating full-scale airspeeds up to 750 miles per hour (when compressibility effects were neglected). When stabilized with fins, the model descended to the floor of the tunnel in stable nose-forward flight; whereas without fins it turned away from a nose-first flight attitude. In another instance (results unpublished), duplicates of two of the free-spinning-tunnel models were fired with and without stabilizing fins at a Mach number of 1.2 (actual model speed) in a Langley free-flight apparatus, and the results obtained were similar to those obtained during the atmospheric horizontal wind-tunnel tests. In another investigation (reference 6), the Langley Pilotless Aircraft Research Division stabilized a large model of one of the free-spinning-tunnel nose sections with fins selected on the basis of the free-spinning-tunnel investigation and forcibly jettisoned the nose from an afterbody of a test rocket in flight at a Mach number of about 0.87. The nose traveled stably after leaving the afterbody.

Although, as previously mentioned, a pilot jettisoned at transonic speeds in a stabilized nose would not be subjected to excessive accelerations, at high supersonic speeds it is conceivable that even a stabilized nose may require the use of a controlled auxiliary propulsive force to allow a gradual decrease in airspeed and thus prevent decelerations high enough to endanger the pilot.

CONCLUDING REMARKS

An empirical criterion based on investigations of five jettisonable nose configurations in the Langley 20-foot free-spinning tunnel has been developed which indicates the fin area required for stabilizing an airplane jettisonable nose section.

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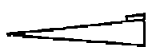
TABLE I.– RÉSUMÉ OF TESTS IN THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL OF MODELS SIMULATING AIRPLANE JETTISONABLE NOSE SECTIONS WITHOUT STABILIZING FINS

Model	n	Sketch	Mass characteristics					Behavior of model
			Weight (lb)	Center-of-gravity location (percent L)	k_x/L	k_y/L	k_z/L	
1	1.90		0.704	69.2	0.141	0.256	0.256	Tumbled end over end about lateral or normal axis with axis in an approximately horizontal attitude
2	1.90		0.623	57.0	0.179	0.321	0.321	Tumbled end over end about lateral or normal axis with axis in an approximately horizontal attitude
3	2.79		0.460	67.0	0.141	0.316	0.305	Rolled about longitudinal axis with axis in an approximately horizontal attitude or Tumbled about normal axis with axis in an approximately horizontal attitude
4	3.80		0.300	55.0	-----	-----	-----	Rotated or oscillated about various model axes in inconsistent manner
5	5.85		0.354	71.9	0.066	0.334	0.334	Rolled about longitudinal axis with nose approximately 35° up from horizontal; at same time, rotated about wind axis

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[redacted]

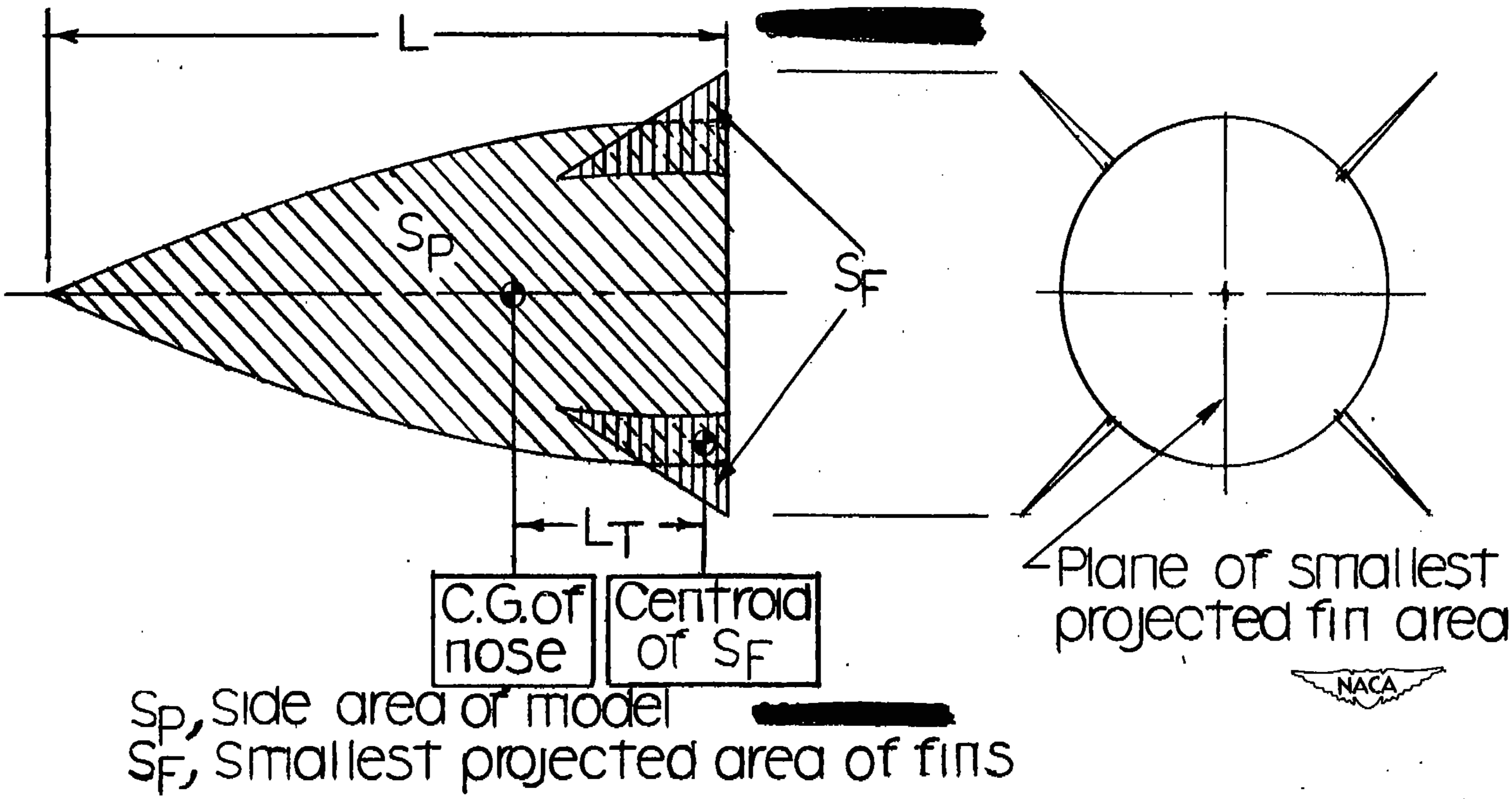

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Figure 1.- Illustration of method of computing fin-stabilization factor $\frac{S_F L_T}{S_P L}$.

[redacted]

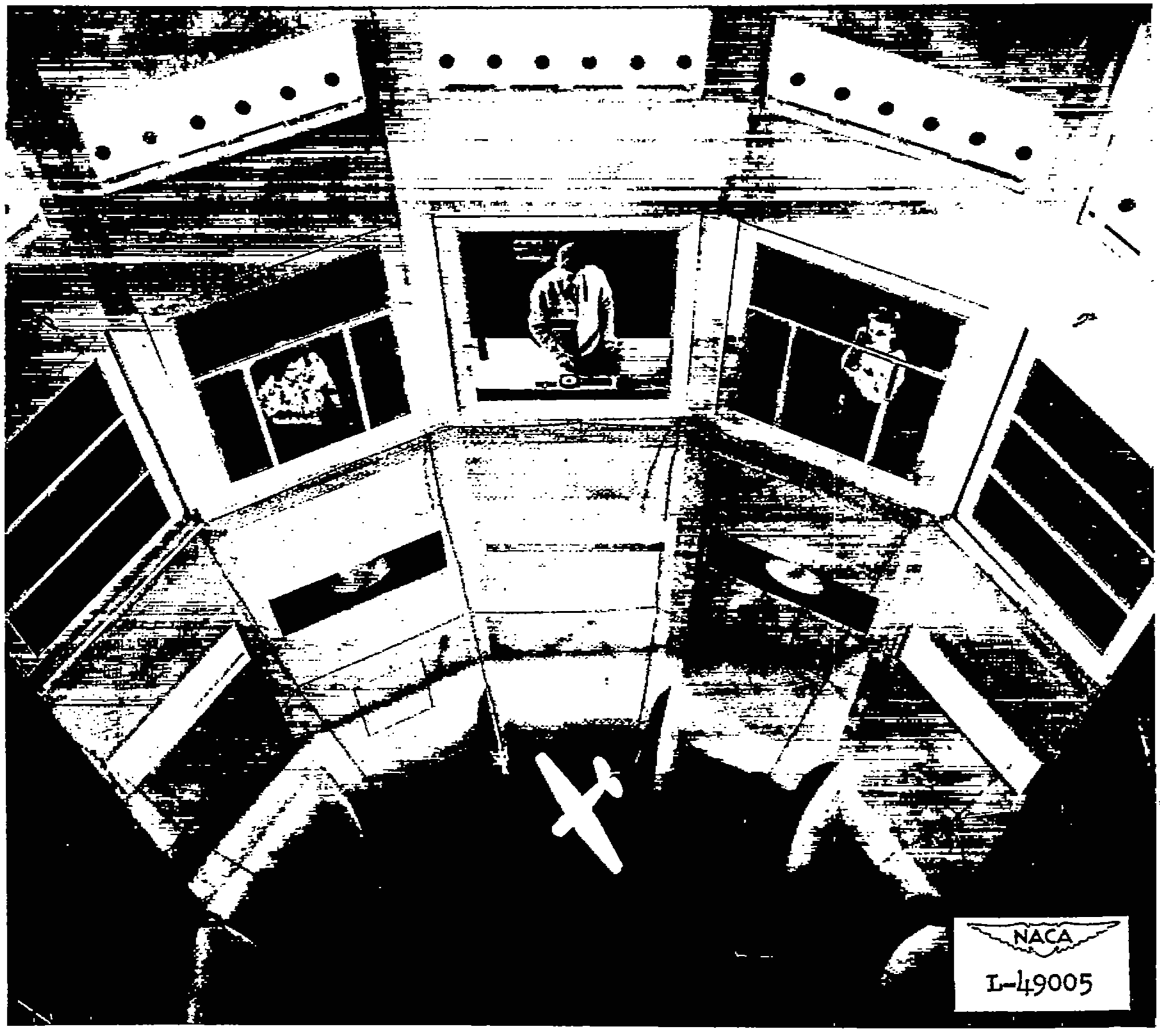

Figure 2.- Photograph of the test section of the Langley 20-foot free-spinning tunnel with an airplane model spinning in the tunnel.

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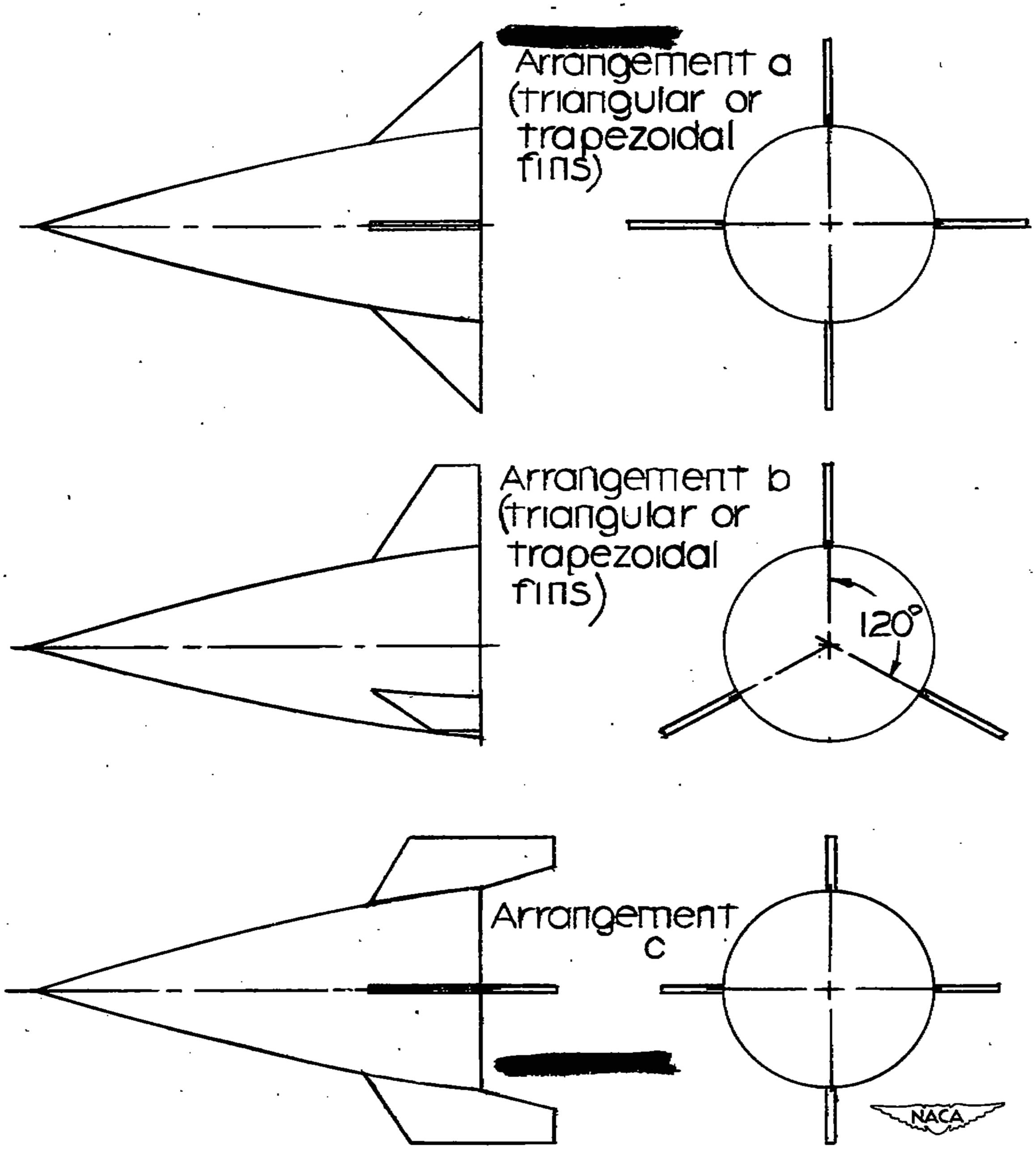

Figure 3.- Sketches illustrating various fin arrangements tested on the models in the Langley 20-foot free-spinning tunnel (models tested are not shown).

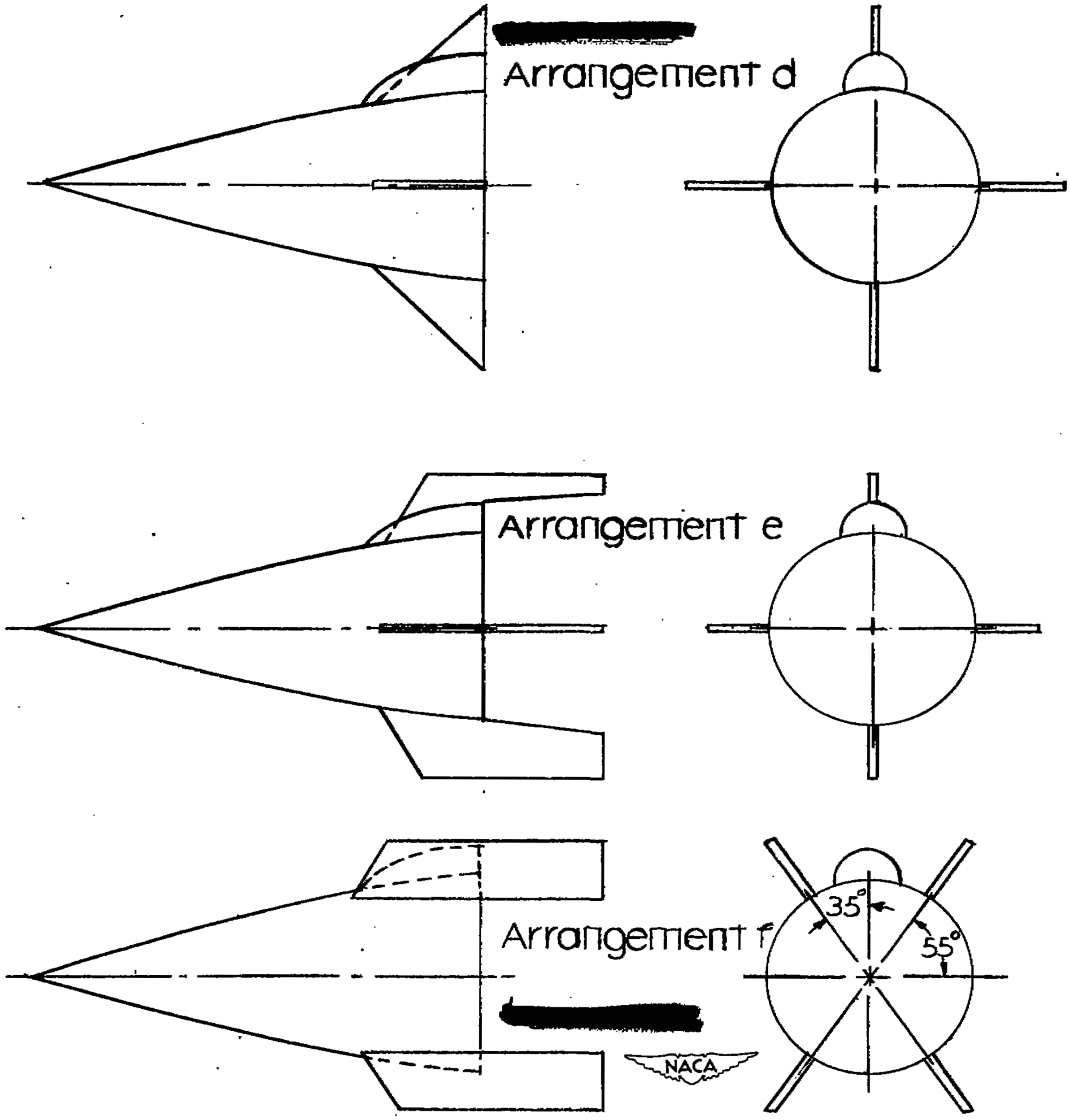

Figure 3.- Continued.

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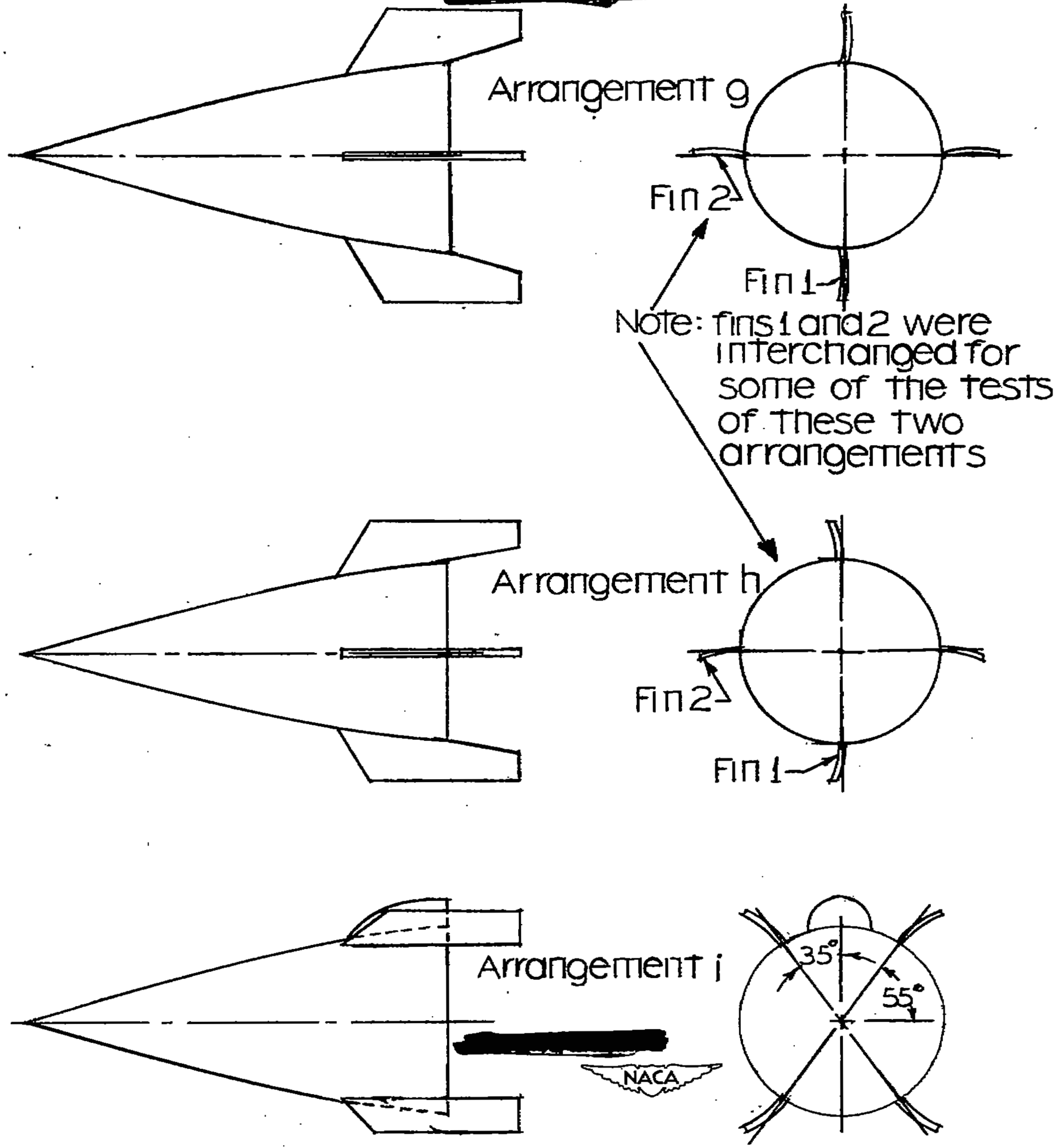

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Figure 3.- Concluded.

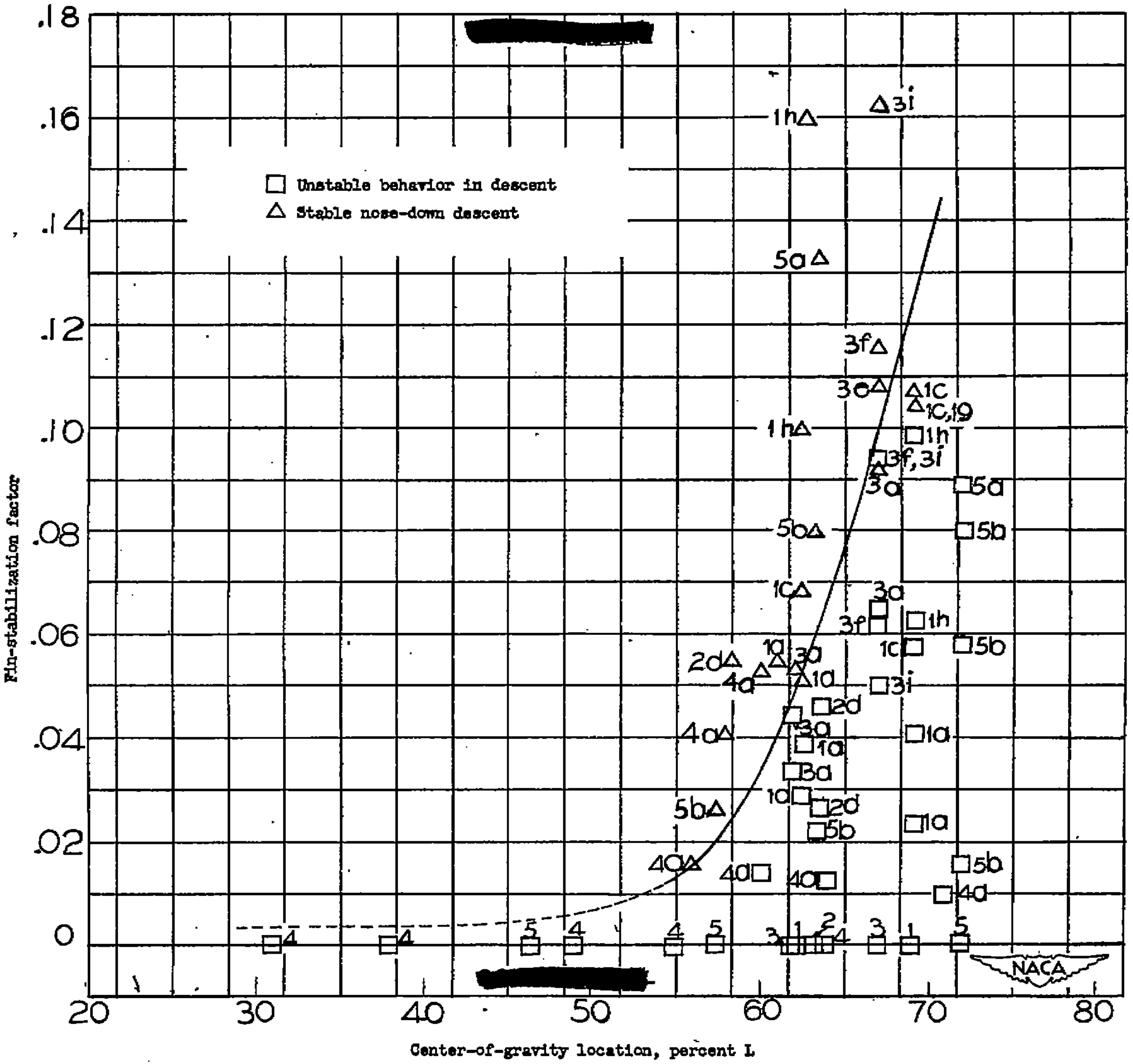

Figure 4.- Effect of fin-stabilization factor and center-of-gravity location on behavior of jettisonable nose sections. (Numbers refer to models listed in table I and letters refer to fin arrangements shown in fig. 3.)

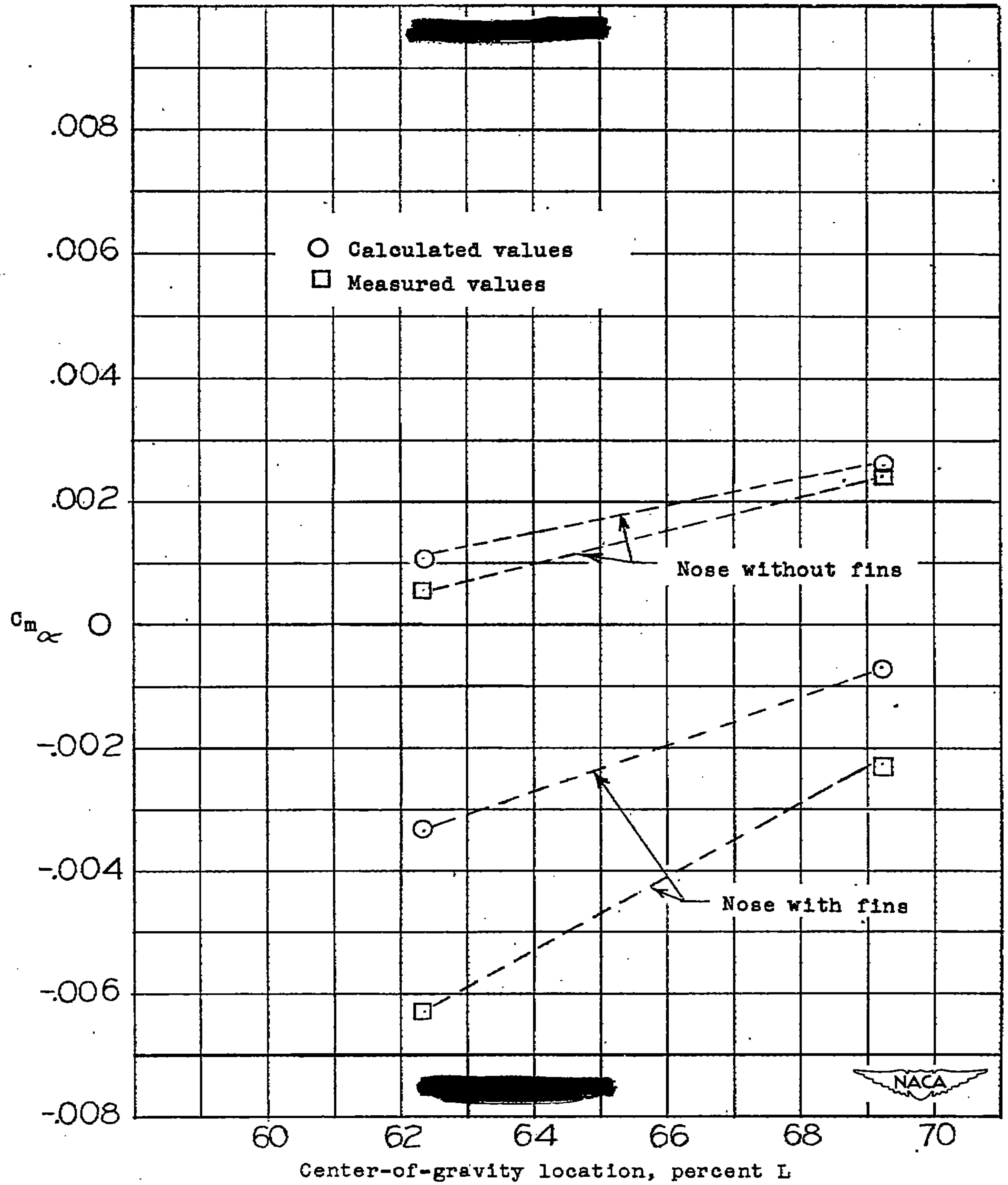

Figure 5.- Calculated and measured values of C_{m_α} for model 1 with and without stabilizing fins of arrangement a installed.